

ELEMENTary Education¹

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GREETINGS! I AM THE OWL-CHEMIST. I'M HERE TO TALK ABOUT WHERE SCIENTISTS THINK THE ELEMENTS CAME FROM.

GET IT? OWL-CHEMIST? ALCHEMIST?

OKAY, YEAH I THINK THEY GET IT.

MAYBE WE'LL LEARN HOW TO MAKE GOLD!

THE STORY STARTS WITH THE **BIG BANG**, ABOUT 15 BILLION YEARS AGO. THE PERIODIC TABLE WAS EMPTY. IT WAS JUST A POSSIBILITY WAITING TO HAPPEN.

THEN SUDDENLY...

BANG!

ALL THE MATTER IN THE UNIVERSE EXPLODED FROM A SINGLE POINT.

AT FIRST THE UNIVERSE WAS TOO HOT FOR MATTER TO BECOME AT ALL ORGANIZED.

WITHIN A FEW SECONDS, THOUGH, PROTONS, NEUTRONS & ELECTRONS FORMED...

...AND THEN SO DID HYDROGEN ATOMS.

ZING!

WUMPI!

WITHIN THE FIRST 3 MINUTES...

1

2

3

POW!

WHOA! I FEEL LIKE A WHOLE NEW ELEMENT.

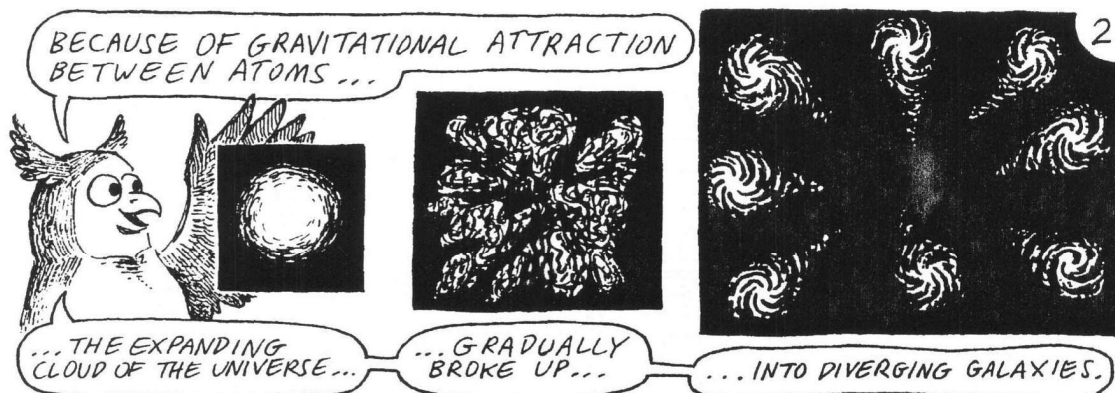
3 MINUTES AFTER THE BIG BANG, THE PERIODIC TABLE LOOKED LIKE THIS:

HYDROGEN ATOMS SLAMMED TOGETHER...

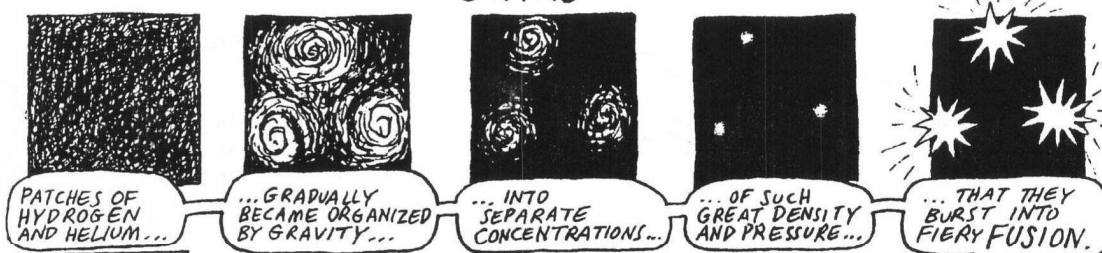
... IN A NUCLEAR REACTION...

... RESULTING IN NUCLEOSYNTHESIS!

THEN, FOR MILLIONS OF YEARS, THE UNIVERSE WAS JUST A RAPIDLY EXPANDING CLOUD OF HYDROGEN AND HELIUM, WITH NO OTHER ELEMENTS.



SOME 5 BILLION YEARS AFTER THE BIG BANG, ABOUT 100 BILLION GALAXIES HAD FORMED. THE PROCESS OF FRAGMENTATION CONTINUED WITHIN EACH GALACTIC GAS CLOUD, FORMING BILLIONS OF STARS:



3

PRESSURE AND FRICTION IN CONDENSING CLOUDS OF HYDROGEN AND HELIUM HAD TO BRING THE TEMPERATURE TO 10 MILLION DEGREES CELSIUS FOR THE FIRST STARS TO IGNITE. WE'RE TALKING ABOUT TEMPERATURES IN THE CORES – THE CENTERS – OF STARS.

10,000,000°C
H → He

THAT'S 5 1/2 MILLION °F.

OUR OWN SUN IS 1/2 TIMES THAT HOT. IT CONVERTS 700 MILLION TONS OF HYDROGEN INTO HELIUM EACH SECOND. HERE ARE A FEW STELLAR NUCLEAR REACTIONS:

$${}^1_1\text{H} + {}^1_1\text{H} \rightarrow {}^2_2\text{He} + \text{energy}$$

$${}^3_2\text{He} + {}^3_2\text{He} \rightarrow {}^4_2\text{He} + 2 {}^1_1\text{H} + \text{energy}$$

THE MORE MASSIVE THE STAR, THE HIGHER ITS CORE TEMPERATURE CAN CLIMB.

3,000,000,000°C
MORE ELEMENTS

HOT!

COOL!

$${}^4_2\text{He} + {}^4_2\text{He} \rightarrow {}^8_4\text{Be} + \text{energy}$$

$${}^8_4\text{Be} + {}^4_2\text{He} \rightarrow {}^{12}_6\text{C} + \text{energy}$$

$${}^{12}_6\text{C} + {}^4_2\text{He} \rightarrow {}^{16}_8\text{O} + \text{energy}$$

AND SO ON...

SEVERAL BILLION YEARS AFTER THE BIG BANG – & SEVERAL BILLION YEARS BEFORE THE PRESENT – THE PERIODIC TABLE LOOKED LIKE THIS:

THIS IS AS FAR AS NUCLEOSYNTHESIS IN THE CORE OF STARS CAN GO. BUT THE PERIODIC TABLE WAS FAR FROM FULL, AND MOST OF THE ELEMENTS WERE TRAPPED INSIDE THE STARS.

BUT WAIT! THE DEATH OF STARS MEANS LIFE FOR CHEMISTRY

THROUGHOUT THE LIFE OF EVERY STAR THE INWARD FORCE OF GRAVITY IS AT ODDS WITH THE OUTWARD FORCE OF PRESSURE. STARS BALANCE BETWEEN COLLAPSE AND EXPLOSION...

AT SOME POINT, THOUGH, A STAR USES UP ITS FUEL, AND EITHER GRAVITY OR PRESSURE MUST PREVAIL.

IF A STAR IS EXTREMELY MASSIVE, GRAVITY WINS... THE STAR COLLAPSES INTO A "BLACK HOLE," AN INTENSELY POWERFUL CENTER OF GRAVITATIONAL ATTRACTION FROM WHICH NOT EVEN LIGHT CAN ESCAPE.

BUT IN OTHER STARS, PRESSURE WINS OUT: THEY EXPLODE INTO SO-CALLED SUPERNOVAS!

SUPERNOVAS ALLOW SEVERAL IMPORTANT THINGS TO HAPPEN.

THEY PROVIDE THE CONDITIONS TO SYNTHESIZE EVEN MORE ELEMENTS, BRINGING THE TABLE TO THIS POINT:

SUPERNOVAS BLOW THEIR SURFACE ATOMS INTO OUTER SPACE, LIBERATING THE ELEMENTS FROM THE STARS

FINALLY, IN THE RELATIVE QUIET OUTSIDE THE STARS, CHEMISTRY CAN REALLY TAKE OFF. INSTEAD OF NUCLEAR REACTIONS, CHEMICAL REACTIONS CAN OCCUR:

$$2\text{H} + \text{O} \rightarrow \text{H}_2\text{O}$$

hydrogen oxygen water

AND THAT'S THE GENERAL STORY OF HOW THE ELEMENTS CAME TO BE — EXCEPT THAT 15 BILLION YEARS AFTER THE BIG BANG, ON A SMALL PLANET CALLED EARTH, HUMAN SCIENTISTS BEGAN TO PRODUCE TINY AMOUNTS OF NEW, UNSTABLE ELEMENTS.

SO WHICH DO YOU THINK WOULD BE EASIER & CHEAPER — SYNTHESIZING A BRAND NEW BATCH OF GOLD FROM OTHER ELEMENTS, OR JUST DIGGING MORE OLD GOLD OUT OF THE GROUND?



UM... I'LL JUST GO GET MY PICK AND SHOVEL.



BETTER YET, LET'S FORGET ABOUT GOLD AND SEE WHAT WE CAN MAKE USING CHEMICAL REACTIONS. MAYBE WE'LL MAKE SOMETHING AS GOOD AS GOLD!

